Olbers Paradox

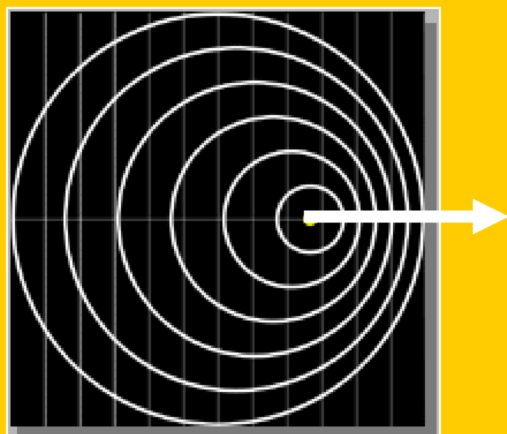
- Why is the sky dark?
  - If the universe were infinitely big and infinitely old, there should be no dark patches in the sky
  - (Heinrich Wilhelm Olbers (1757--1840))
- Possible answers:
  - Dust? No, the dust would heat up and re-radiate the light
  - Finite number of stars? No, there are still plenty to light up the whole sky
  - Intensity of star prop ~ 1/r^2, so distant stars are just not as bright.
  - But volume of space (and so number of stars) grows as r^3!

Here is a picture of the Virgo Cluster courtesy of Matt BenDaniel. Check out his webpage at http://www.starmatt.com.

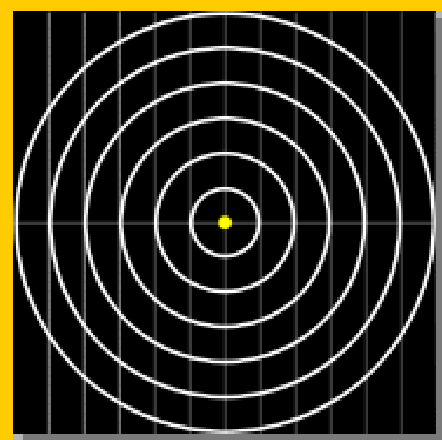
Resolution

- Two answers, which were not appreciated at the time
  - The universe is not infinitely old.:It is now known that the universe is only 10 billion years old , so we can only observe stars that are within 10 billion light years
  - The space-time of the universe is expanding, and as a consequence of this, the most distant stars in the observable universe are moving away from us at a velocity approaching the speed of light. This has the effect of further diminishing the intensity of their light, as obsevered from Earth.
  - http://www.curiouser.co.uk/paradoxes/olbers.htm

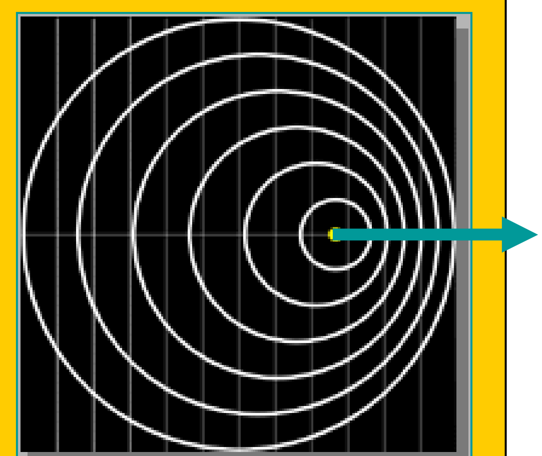
- What evidence is there for this?



Wavelength is shorter when approaching



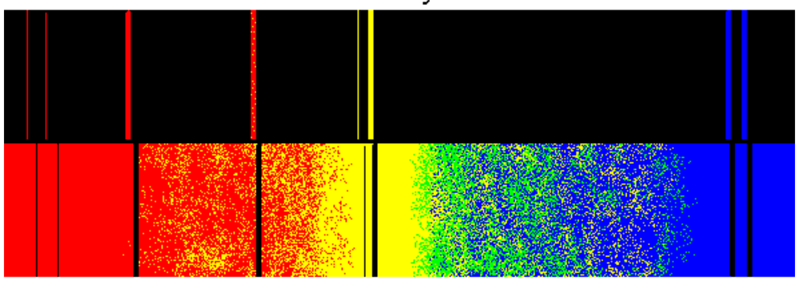
Stationary waves



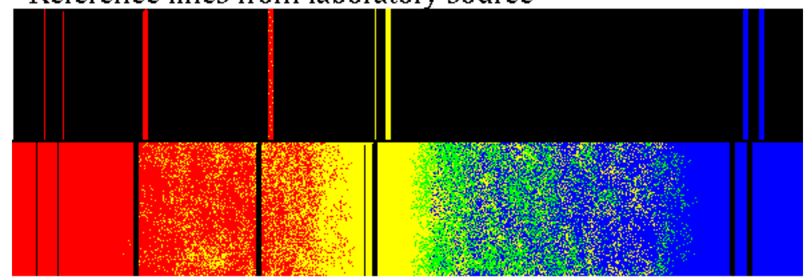
Wavelength is longer when receding

Red Shifted "Spectrum"

Stars moving toward us look "bluer"



Stars moving away from us look "redder"

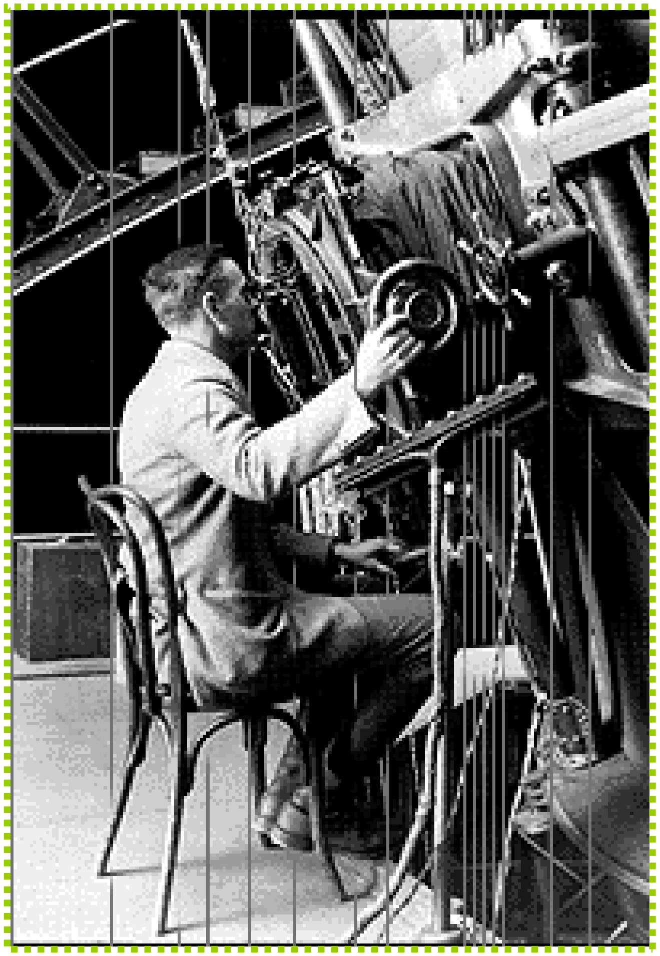


Define "redshift" as the percentage that the wavelength has changed

$$z = \frac{\Delta\lambda}{\lambda} = \frac{\lambda - \lambda_o}{\lambda_o} = \frac{v}{c}$$

If "z" is larger, then the object we are looking at is moving faster AWAY from us.

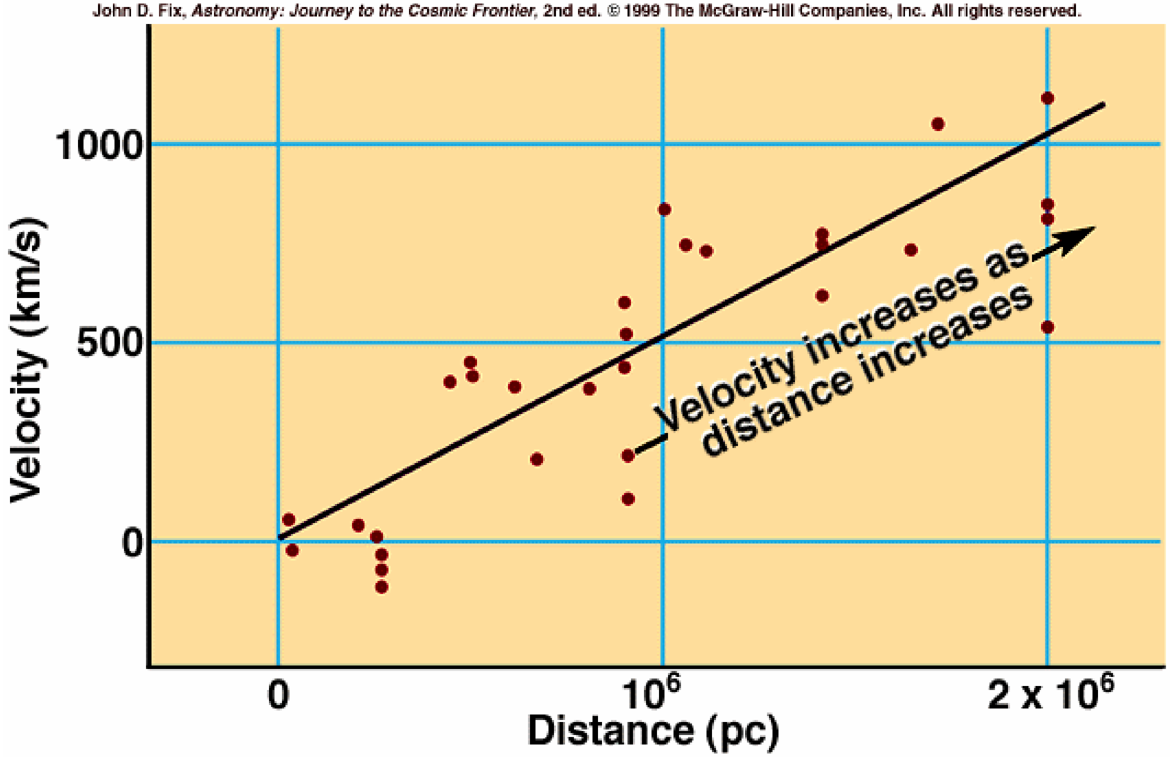
Hubble



In 1929 American astronomer Edwin Hubble studied the redshift of galaxies, and found that whichever direction a galaxy is in:

the recession velocity (redshift) increases the farther away an object is

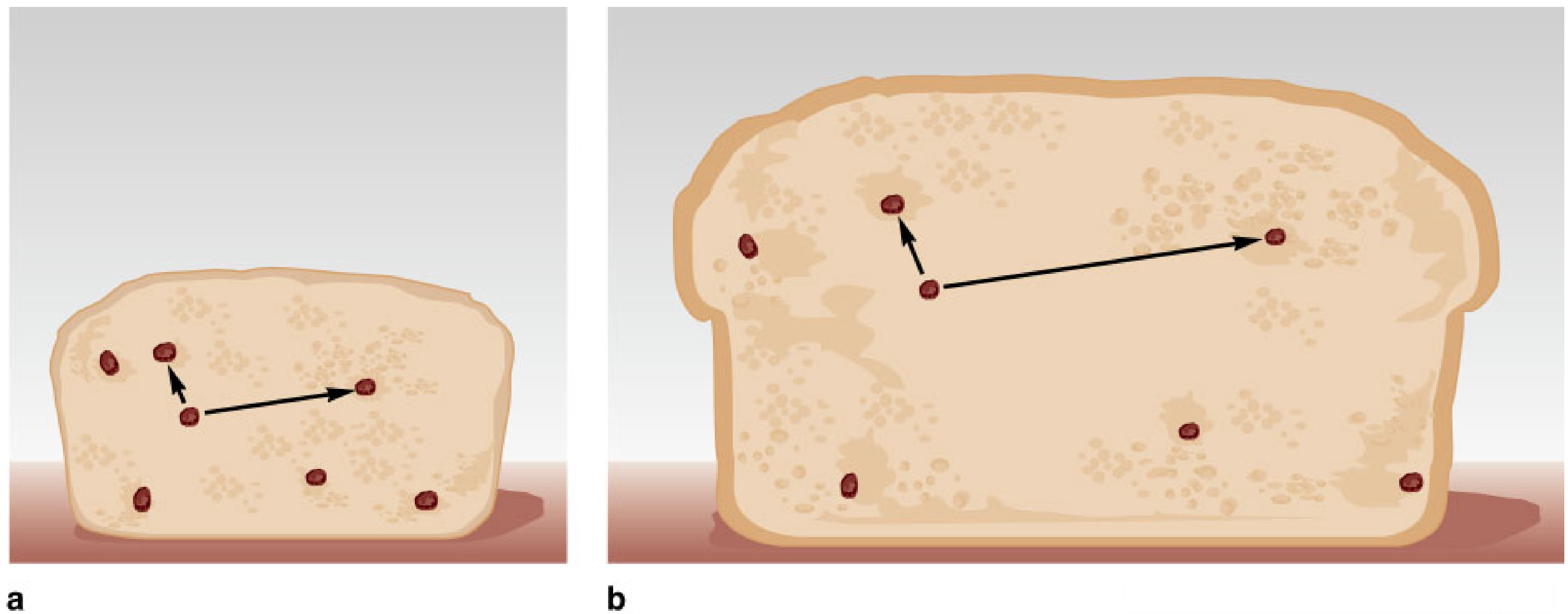
$$v = H_0 d$$



Edwin Hubble's plot of the velocities and distances of galaxies.

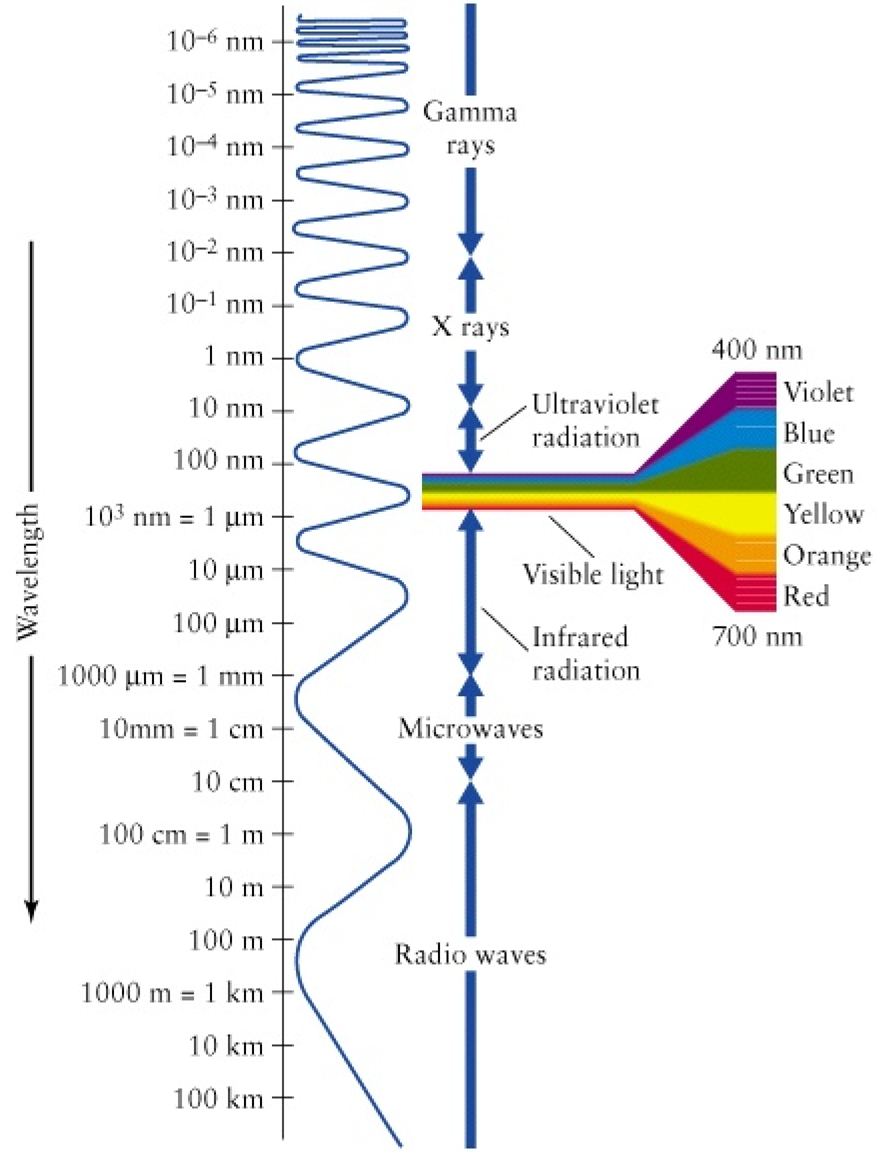
Are we at the center of the Universe?

- Ummmm… NO!
- Think of raisin bread baking. Every raisin will see all the other raisins moving away as the bread expands.
- No raisin is "special".



The Expanding Universe

- Why are stars far away from us "red-shifted"
- It is NOT because they are moving away from us – although that is a possible interpretation
- Instead space itself is expanding as time moves forward
- So a photon emitted with a given wavelength – say close to blue in the diagram – gets "stretched out" as it travels to us. Its wavelength gets longer!
- So the red-shifting is due to space itself expanding!

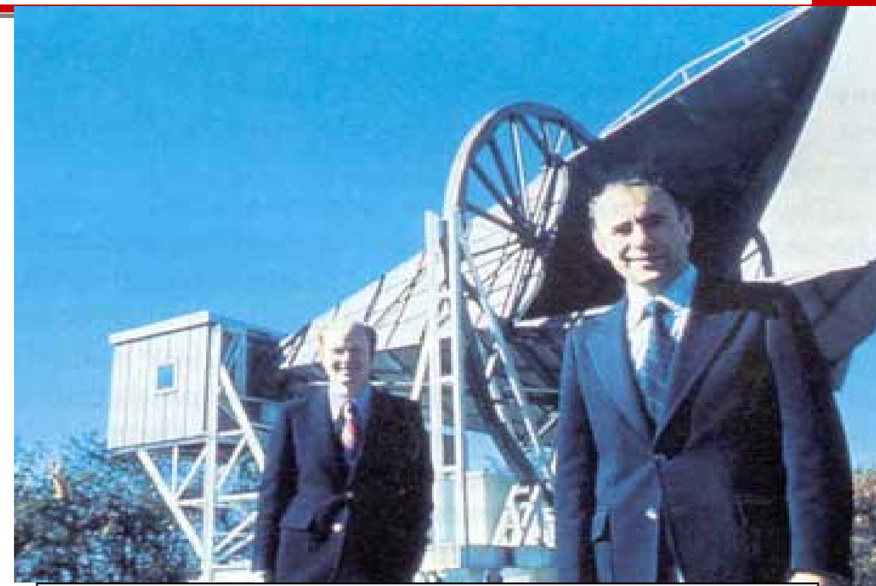


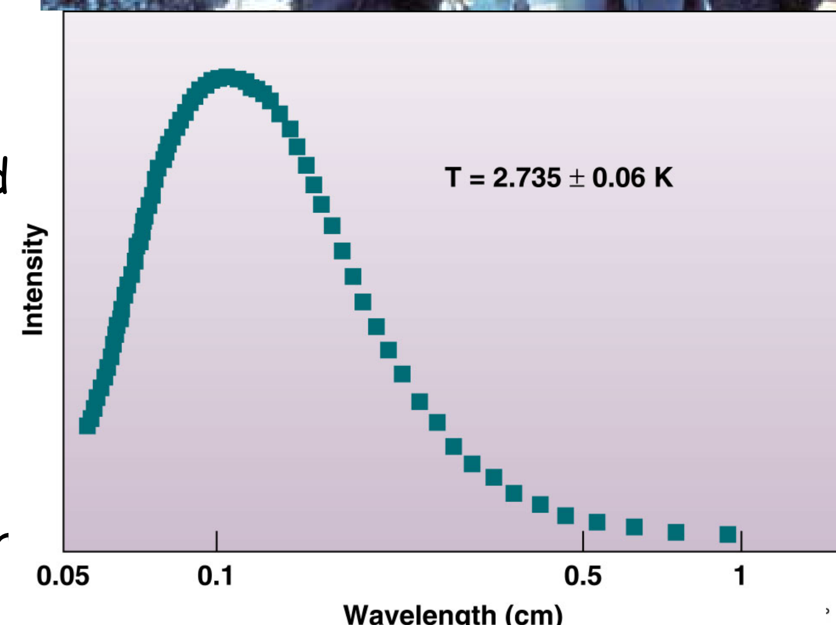
Expanding Universe!

- RussianAmerican physicist George Gamow: if all galaxies are moving away from all others, then universe must have been at a point some time in the past.
- Fred Hoyle: Thinks Gamow's idea is bogus. Refers to Gamow's idea as "The Big Bang"
- Only problem: everybody likes the name…and George is right!
- But how would we know? Gamow predicted there would be a leftover "buzz" or radiation signature from the Big Bang.
- This buzz would be equivalent to the radiation given off by an object (a "black body") with a temperature of a few Kelvin

The Cosmic Microwave Background Radiation

- In the 1960s Arno Penzias and Robert Wilson were working at AT&T Bell Laboratories, trying to improve microwave communications by reducing antenna noise. They found a noise in their antenna they simply couldn't remove. They considered all kinds of possibilities including bird droppings, but nothing helped. If the antenna was pointed at the sky, the noise appeared. The pointing direction and time of day didn't matter. Finally they called an astrophysicist at Princeton, who told them what the signal probably was, hung up the phone, turned to his associates and said, "We've been scooped." The annoying noise was, in fact, the primordial radiation left over from the Big Bang. Penzias & Wilson won the Nobel Prize for their discovery.

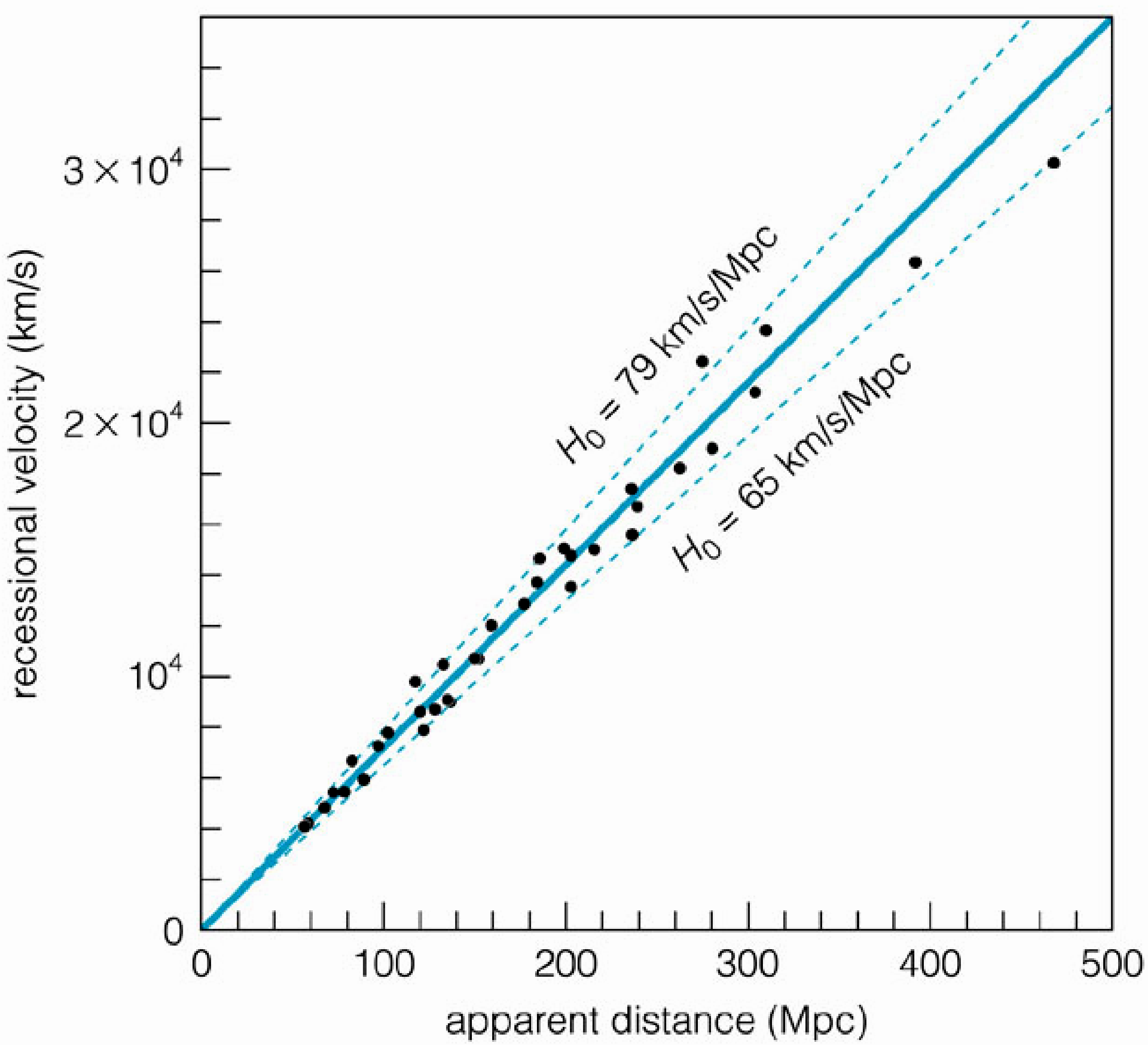




Big Bang!

- The Universe began in an episode of high temperature and density about 13 billion years ago.
- Matter, energy and physical laws came into being at that time.
- The Big Bang was <u>not</u> an explosion of matter and energy in pre-existing space.
- Space and time came to be during the Big Bang.
- Physical laws came into being then, too.

Better Measurements of the Hubble Constant



H_o = 71 +/- 4 km/s/Mpc

Hubble (1929) plot extended only to 2 Mpc, H_o was ~500!

Age of the Universe

- H_0 has units of 1/time:

$$H_0 = \text{distance}/(\text{time} \times \text{distance})$$

- $1/H_0$ is the Hubble Time, t_H.
- This is the time since the Big Bang.
- H_0=75 km/sec/Mpc $\rightarrow$ t_H = 13.0 billion years

Big Crunch, or Heat Death?

- Required density for Universe to recollapse: 4.5×10^{-30} g/cm^3 = critical density.
- Observed density of luminous material: 2×10^{-31} g/cm^3.
- But there may be 5× this amount in dark matter.
- The curvature of the universe as a whole is determined by its mass density, Ω.
- A universe with a mass density greater than the critical value, $\Omega > 1$, will be a spherical closed universe.
  - Universe will eventually contract into "big crunch".
- A universe with a mass density $\Omega < 1$will be an open, hyperbolic universe.
  - Universe will expand forever.
- A universe with a mass density $\Omega = 1$will be flat
  - Universe will expand forever, at an ever-decreasing rate.

What kind of universe do we have?

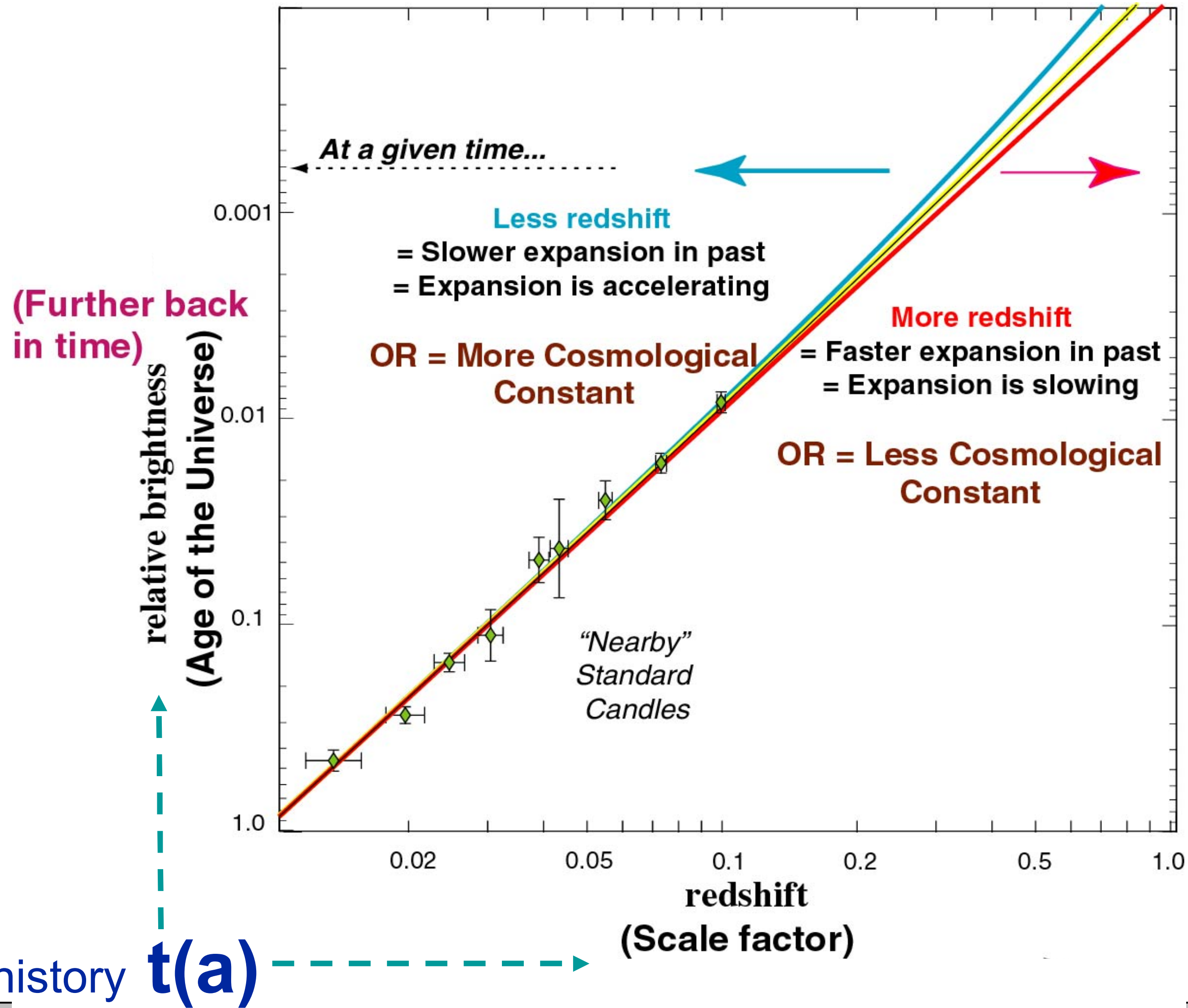
- $\Omega_{LM} + \Omega_{DM} + \Omega_{DE} = \Omega$
- Luminous matter, $\Omega_{LM} \sim 0.05$
- Dark matter, $\Omega_{DM} \sim 0.20$
- Other measurements tell us the the total $\Omega = 1$
  - we live in an flat universe.
- What is Ω_{DE} ?
  - Dark Energy

Dark Energy: How can you "see" it?

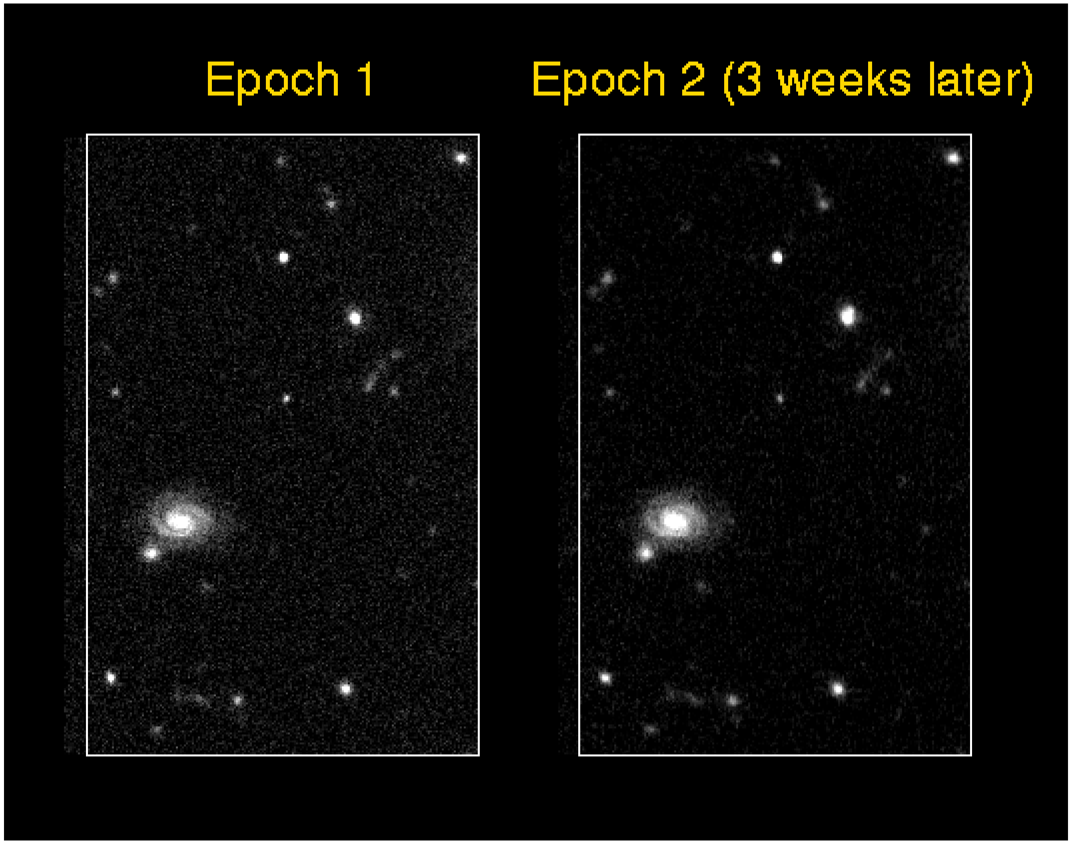
Look at how the expansion is changing over time (at great distances)

- Observations of Type-1a Supernovae (SN1a)
  - Very good "standard candles"
  - Can use them to measure relative distances very accurately
- What produces a SN1a?
  - Start off with a binary star system
  - One star comes to end of its life – forms a "white dwarf" (made of helium, or carbon/oxygen)
  - White Dwarf starts to pull matter off other star… this adds to mass of white dwarf (accretion)
  - Once the mass gets to about 1.4 solar masses – SuperNova!
  - Since white dwarf always has same mass when it exploded, these are "standard candles" (i.e. bombs with a fixed yield)
- The program:
  - Search for SN1a in distant galaxies
  - Compare expected power with observed power to determine distance
  - Measure velocity using redshift

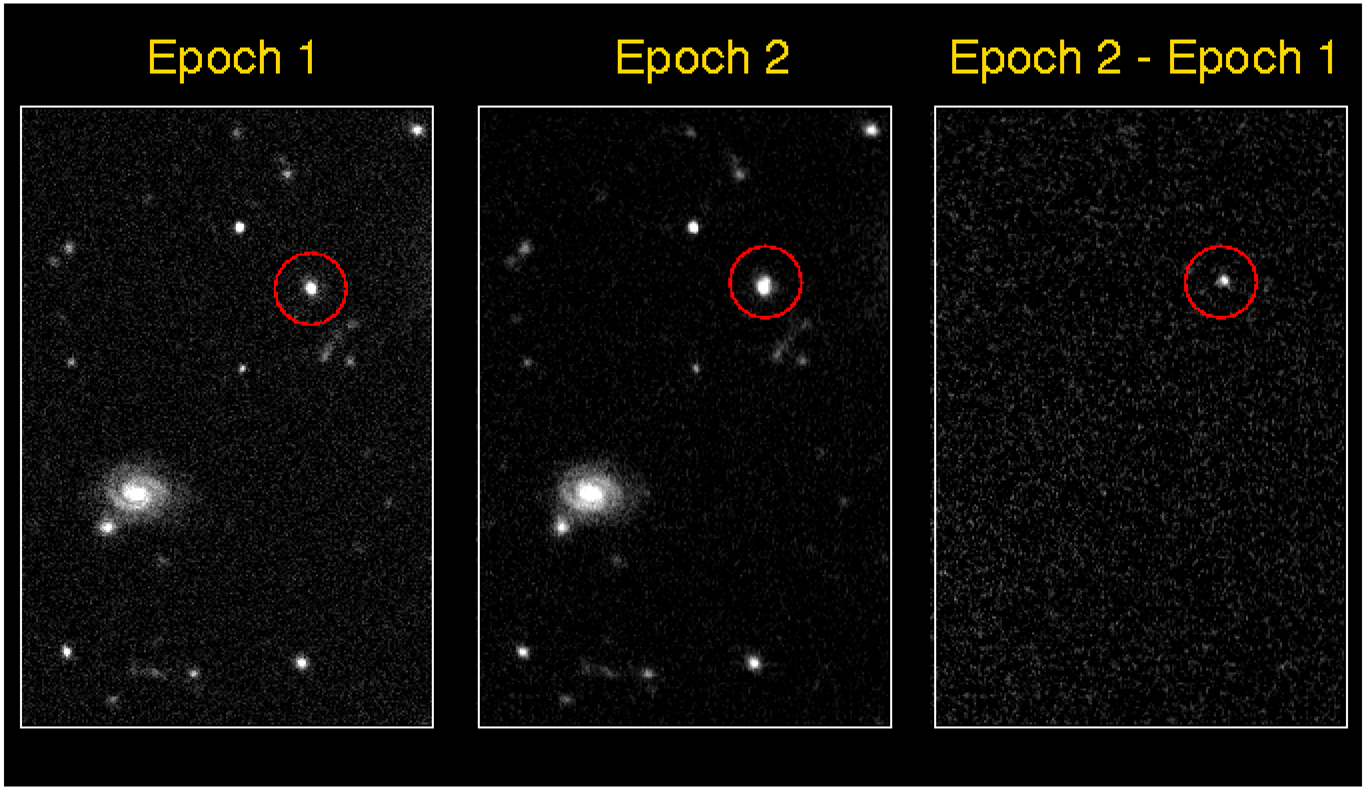
Supernovae map expansion



Finding A SuperNova is Hard!

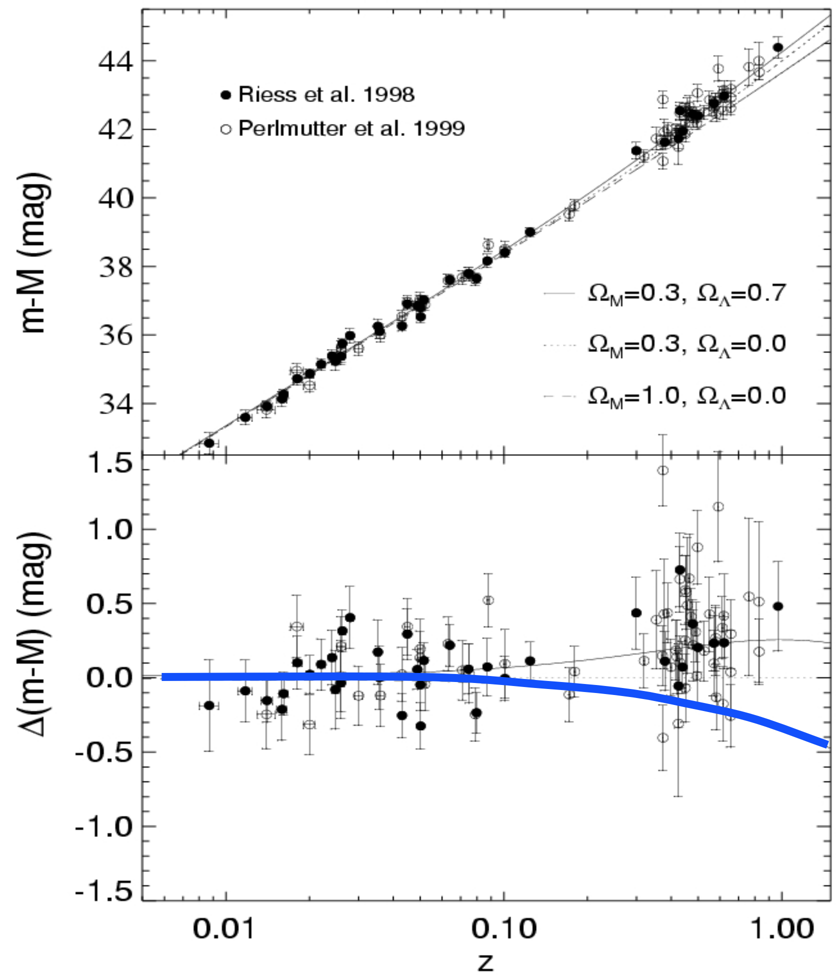


Or maybe it's easy, if you are clever!



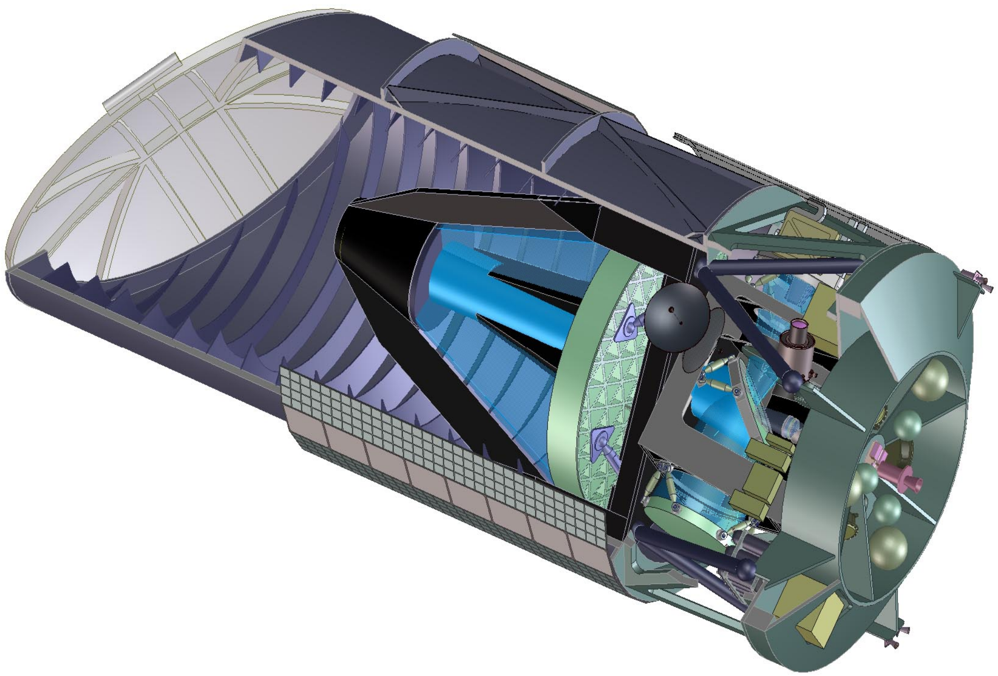
Looking at SuperNovae

- This program gives most accurate value for Hubble's constant
  - H=65 km/s/Mpc
- From Hubble's law you can predict how far away a SN is if you know its redshift
  - But you can measure both the redshift and the distance to the SN
- Find that far distant SN's are NOT as redshifted as expected!
  - Distant SN's are older (looking back in time)
  - Means that older photons did not get as redshited as you expected
  - So in the past the universe expanded less
  - Or equivalently: the expansion of the universe has accelerated
  - DARK ENERGY!



It's a SNAP!

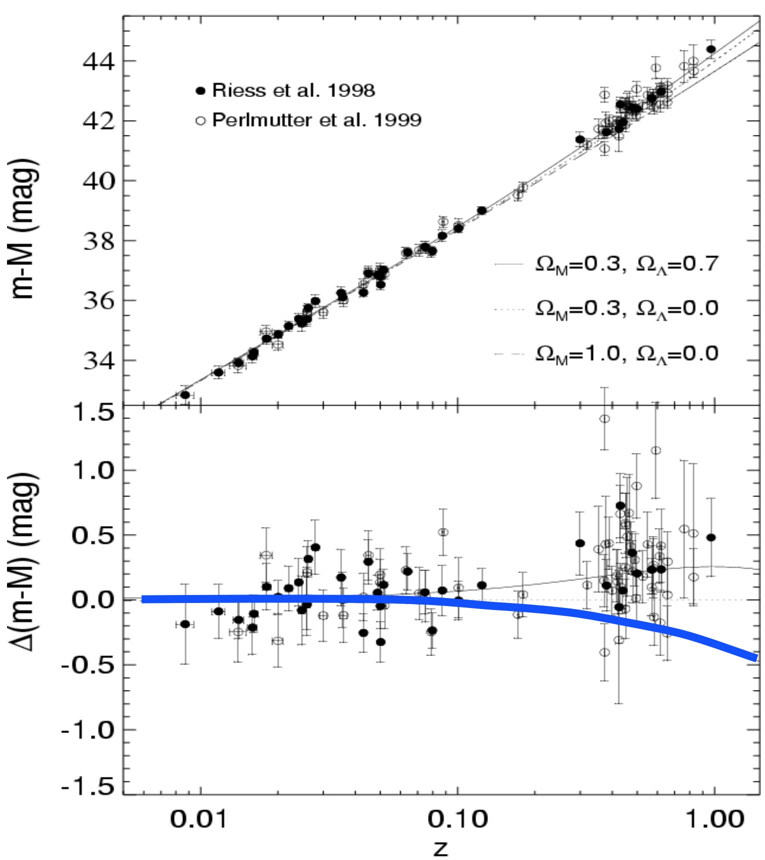
Super Nova Acceleration Probe
Proposed space-based telescope that seeks to discover several extremely distant supernovae
Lawrence Berkeley National Lab & University of California at Berkeley
SNAP would orbit a 3-mirror, 2-meter reflecting telescope in a high orbit over the Earth's poles, circling the globe every 1 or 2 weeks.



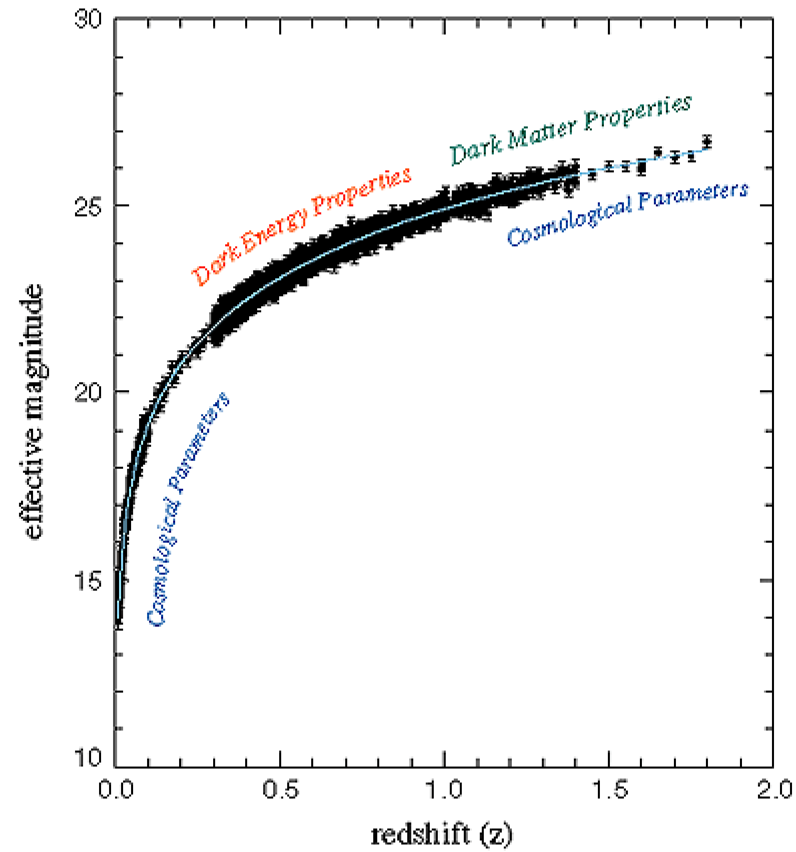
- By repeatedly imaging just one or two large patches of sky, SNAP could gather 2,000 type Ia supernovae in a single year, 20 times the number from a decade of ground-based search. Because of enhanced sensitivity to infrared light above the atmosphere, many of these new supernovae would be at distances and redshifts far greater than any yet found.

How Well Can SNAP do?

Measurements Now



Using SNAP



The Breakdown of the Universe